Sequence Stratigraphic Framework Approach for the Identification and Mapping of Upper Devonian Siltstones in Northern West Virginia, Appalachian Basin*

Craig Eckert[1], Eric G. Ober[1], and Scott McCallum[1]

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Abstract

Vertical wells commingling gas production from upper Devonian siltstone and sandstone reservoirs have been produced for over 100 years in northern West Virginia. The identification and thorough understanding of the siltstone trends as potential resource plays is of great interest to our industry. Methodologies for better mapping and identifying these trends was employed using a sequence stratigraphic approach to best correlate these internal clastic reservoir units.

Discrete stratigraphic sequences were mapped by identifying and correlating fourth order flooding surfaces within the upper Devonian Famennian-Frasnian section of northern West Virginia. These mapped sequences contain mostly distal turbidites, and reveal three dimensional geometries attributable to the subtle, but active movement of re-activated Grenville age basement blocks. Recurrent movement along many of these basement faults and cross-strike discontinuities (CSDs) is reflected in the alignment, morphology and extent of many of these linear turbidite bars.

Evidence for compartmentalization of these tight siltstone reservoirs has been observed in stratigraphically equivalent productive siltstones in southern West Virginia. Reservoir similarities and favorable production results from these siltstone reservoirs lead to the conclusion that similar potential could be expected from the far more extensive northern West Virginia siltstone reservoirs.

References Cited

Boswell, R., 1988, Stratigraphic expression of basement fault zones in northern West Virginia: GSA Bulletin, v. 100/12, p. 1988-1998.

McDaniel, B.A., 2006, Subsurface Stratigraphy and Depositional Controls on Late Devonian-Early Mississippian Sediments in Southwestern Pennsylvania: M.S. Thesis, West Virginia University, 90 p.

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Sequence Stratigraphic Framework Approach for the Identification and Mapping of Upper Devonian Siltstones in Northern West Virginia, Appalachian Basin

Craig Eckert, Eric Ober, Scott McCallum

May 22, 2013

Outline
Upper Devonian Siltstones in Northern West Virginia

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- Geology and Production
- Methodologies
- Mapping Results
- Producing Analogs
- Petrophysical Model
- Summary and Conclusions

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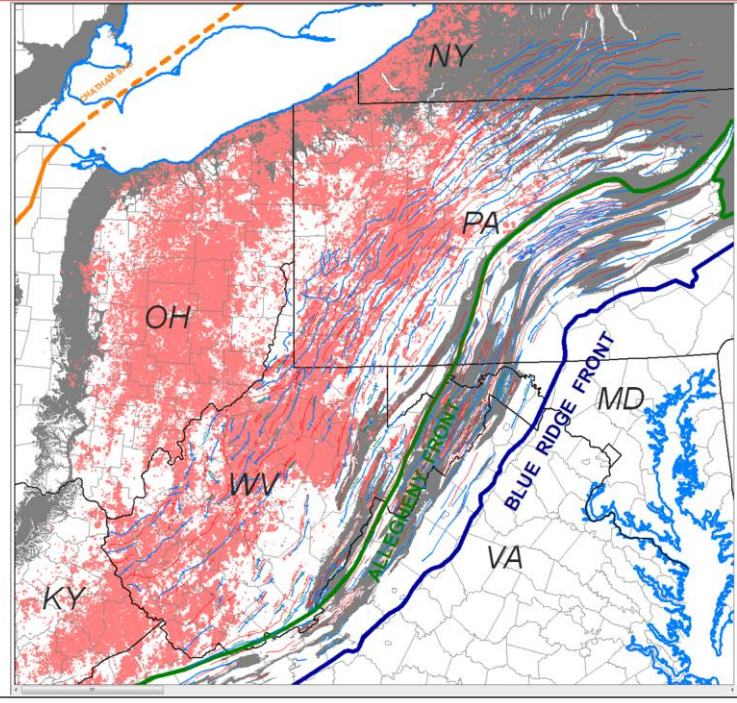
Appalachian Basin Geology
All Production



Anticline
Syncline

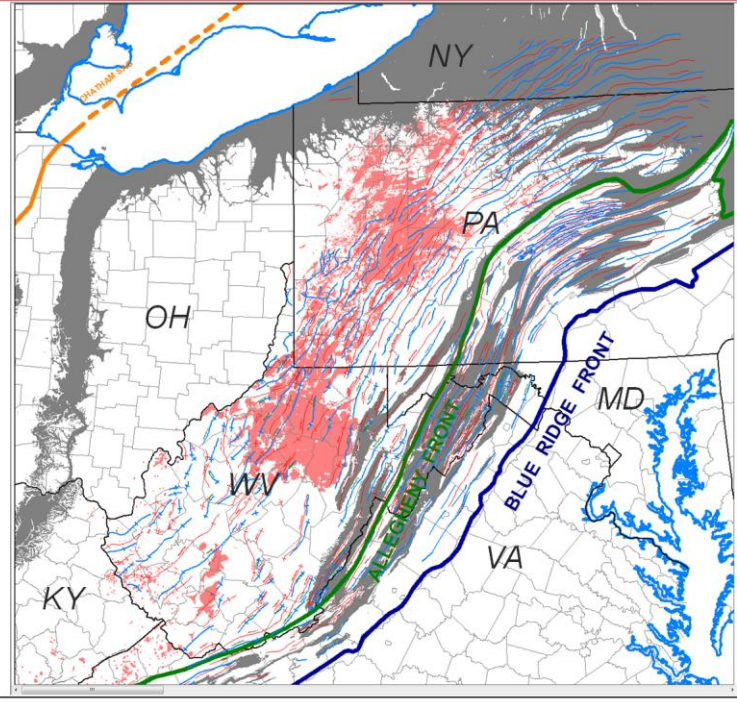
All Fields

Devonian Outcrop

N

60 MI

Appalachian Basin Geology
Upper Devonian Ss and Slts Production



Anticline
Syncline

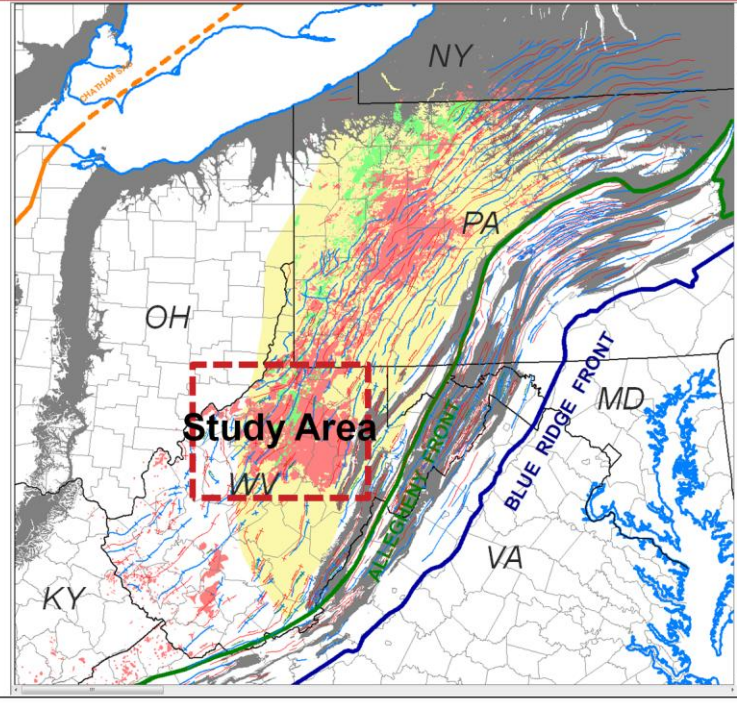
U Dvnn
Ss Fields

Devonian
Outcrop

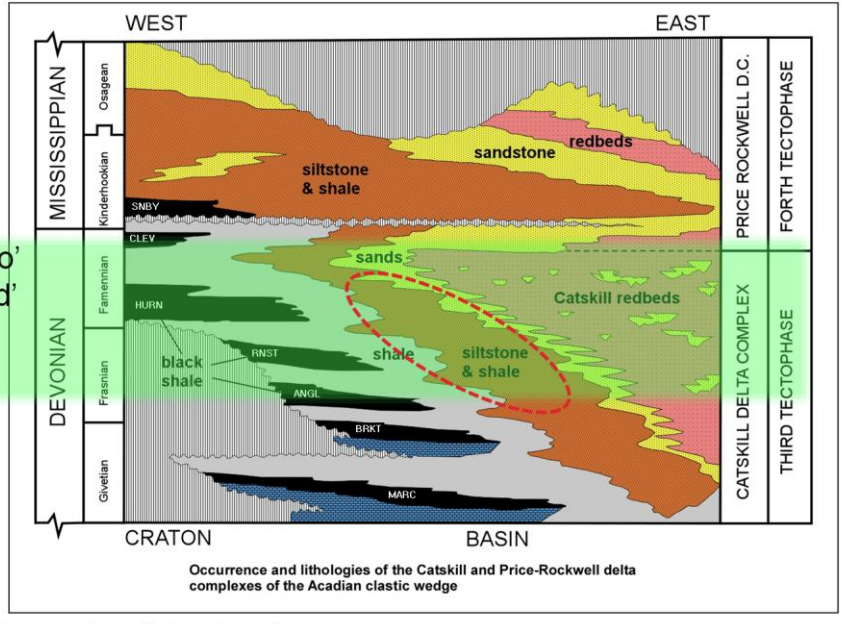
N

60 MI

Appalachian Basin Geology
Upper Devonian Ss and Slts Production, Oil Fields



Upper Devonian Geology
Delta Complexes of the Acadian Clastic Wedge



Occurrence and lithologies of the Catskill and Price-Rockwell delta complexes of the Acadian clastic wedge

'Venango'
'Bradford'
'Elk'

Upper Devonian Matrix plays

from Boswell, 1988

Appalachian Basin Geology

Structure on Basement from Wells and Seismic

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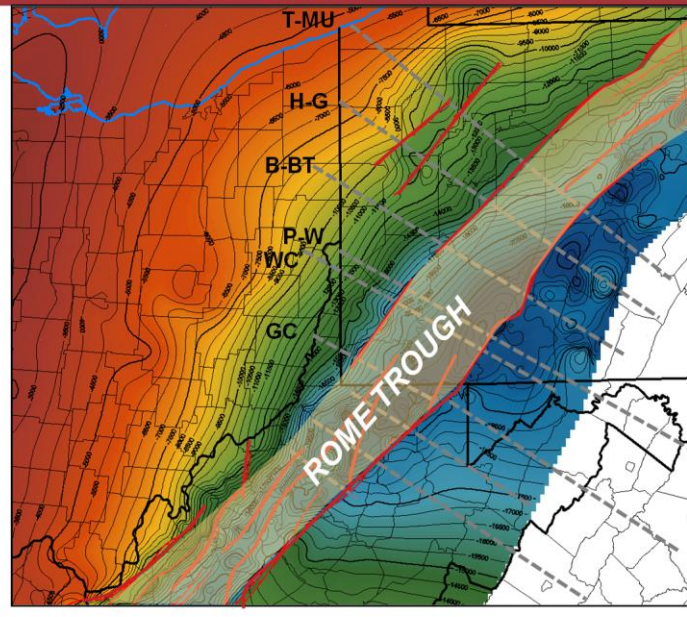

BASEMENT FAULTS AND CSDs
and their influence on Upper Devonian Deposition

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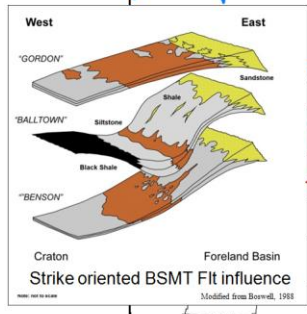

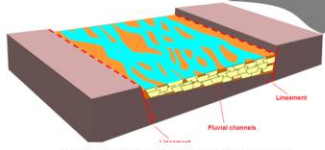

CSDs: Dip oriented BSMT Flt influence from McDaniel, 2006

SEISMIC BSMT FLT

CSD

N

40 MI

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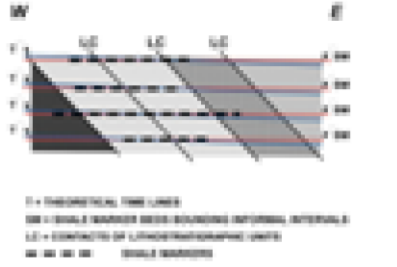
Sequence Stratigraphic Framework

- Sequence Stratigraphic Framework after Galloway
- Flooding surfaces define sequence boundaries
- This method works well in Upper Devonian

Consistent Shale Marker Beds are Roughly Equivalent to Time Markers (Flooding Surfaces)



after Boswell, 1988

Sequence Stratigraphic Cross-section
of the Famenian Stage of Eastern OH to Central WV

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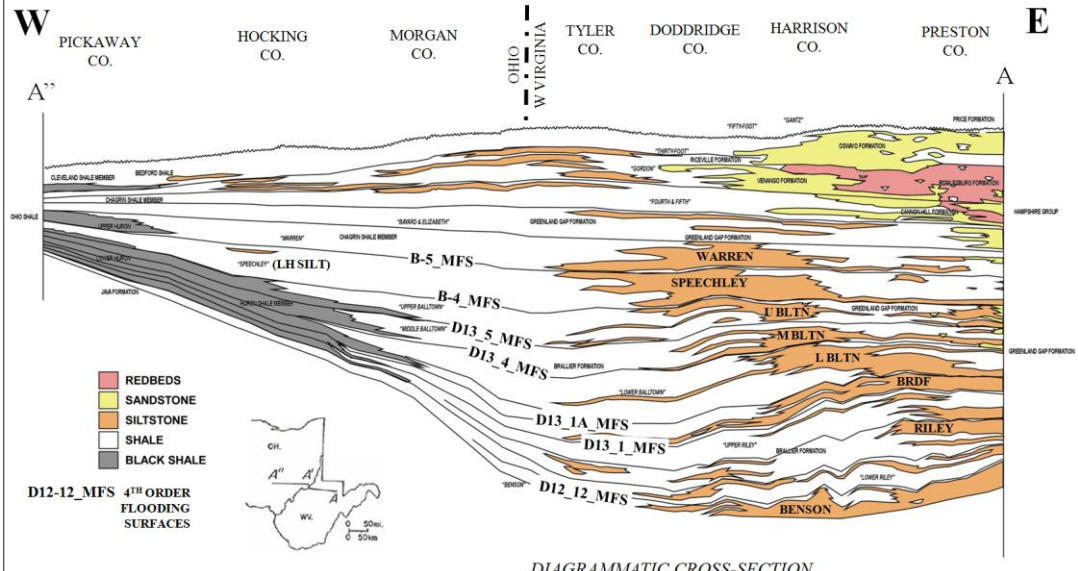

DIAGRAMMATIC CROSS-SECTION

Modified from Boswell, 1988

Upper Devonian Strat Chart showing Sequences and their Internal Reservoir Units

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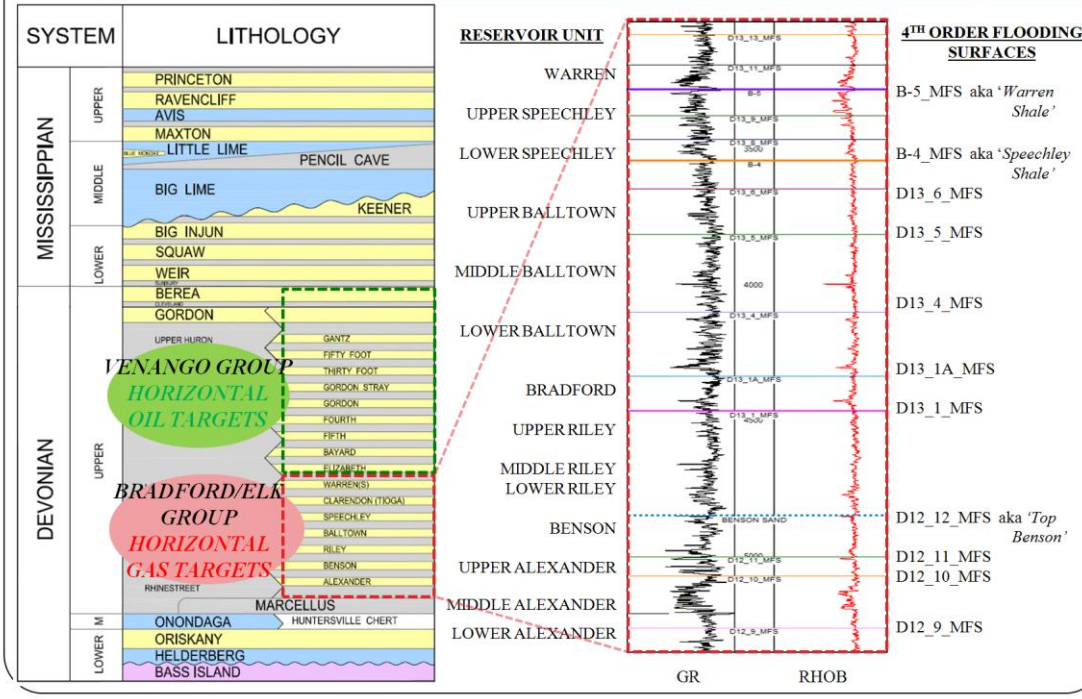
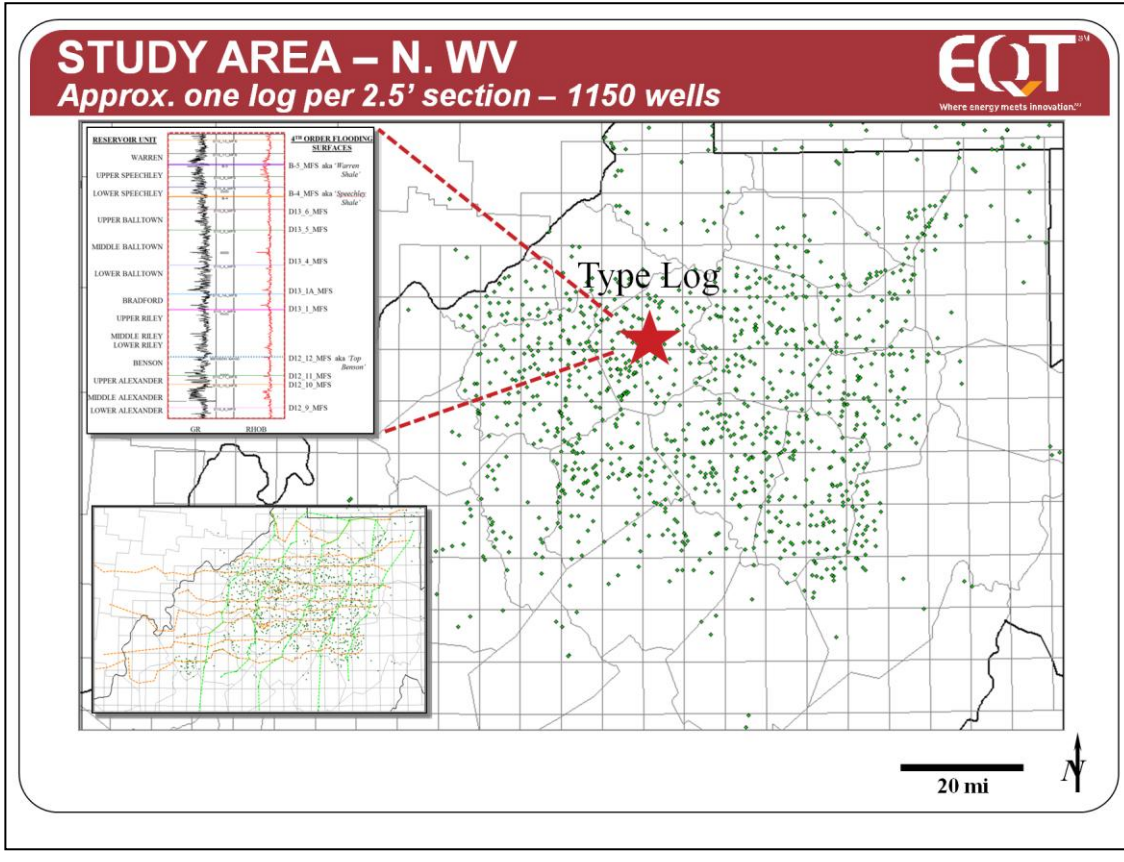
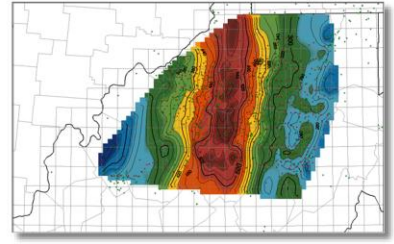


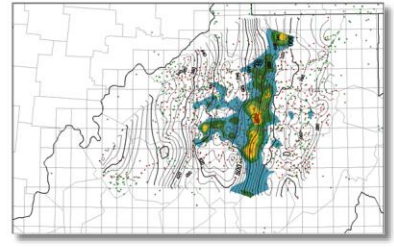


Presenter's notes: ISOPACH B-5_MFS TO B-4_MFS

MID-LOWER FAMENIAN SEQUENCE ISOPACHS

- **Geometry of sequence isopachs reveals morphology of reservoir units contained within**
- **Geometry of sequence isopachs reflects:**
  - Tectonic influence
  - Depositional environment
- **Internal Reservoir units**
  - Net sand
  - Net pay





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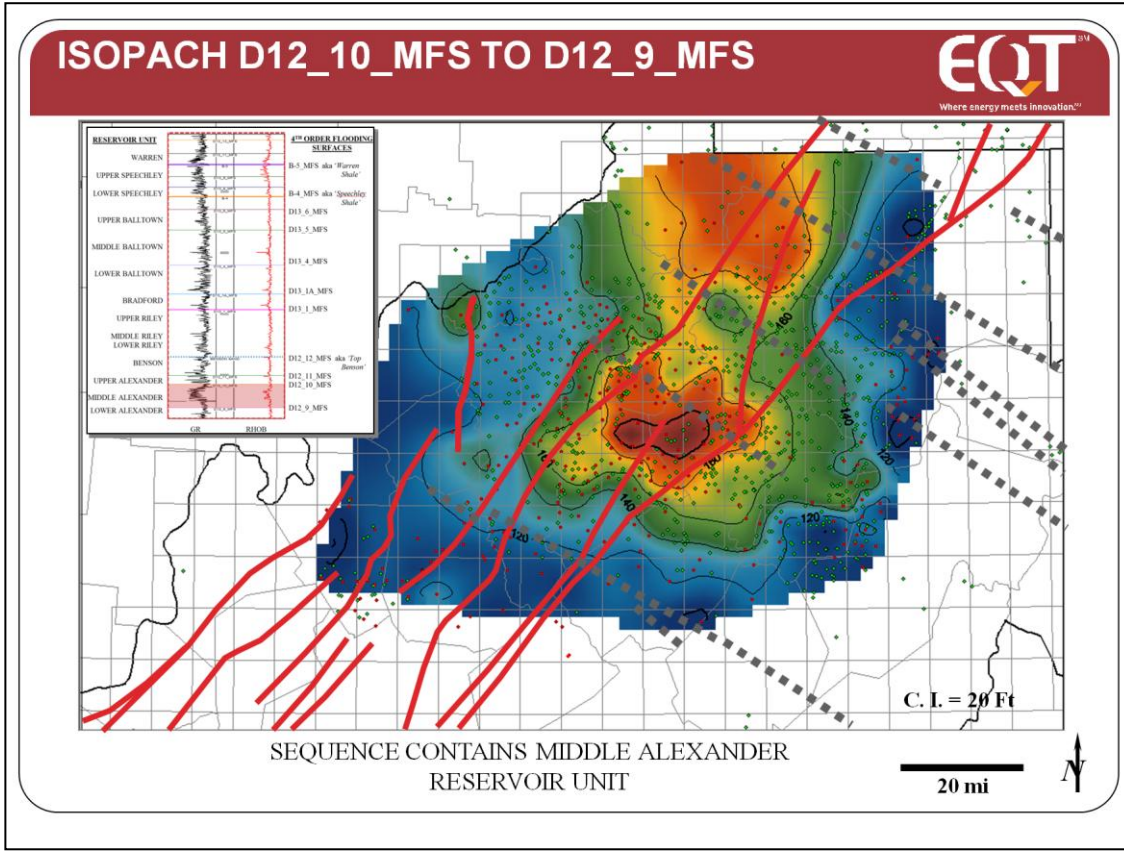
NET PAY INTERVALS MAPPED

- D13_11_MFS to B-5_MFS (Warren)
- D13_10_MFS to D13_9_MFS (Upper Speechley)
- B-4_MFS to D13_5_MFS (Upper Balltown)
- D13_5_MFS to D13_4_MFS (Middle Balltown)
- D13_4_MFS to D13_1A_MFS (Lower Balltown)
- D13_1A_MFS to D13_1_MFS (Bradford)
- D13_1_MFS to D12_12_MFS (Rileys)
- D12_12_MFS to D12_11_MFS (Benson)
- D12_11_MFS to D12_10_MFS (Upper Alexander)
- D12_10_MFS to D12_9_MFS (Middle Alexander)
- D12_9_MFS to D12_8A_MFS (Lower Alexander)
- D12_8_MFS to D12_7_MFS (Upper Elk)
- D12_8A_MFS to D12_8_MFS (Upper Elk)
- D12_7_MFS to D12_MFS (Middle Elk?)
- D12_MFS to D11_MFS (Middle Elk?)
- D11_MFS to D10_6_MFS (Sycamore Grit)
- D11_MFS to D10_MFS (Lower Elk?)
- D10_3_MFS to D10_MFS (Lower Elk)
- D10_6_MFS to D10_3_MFS (Lower Elk)

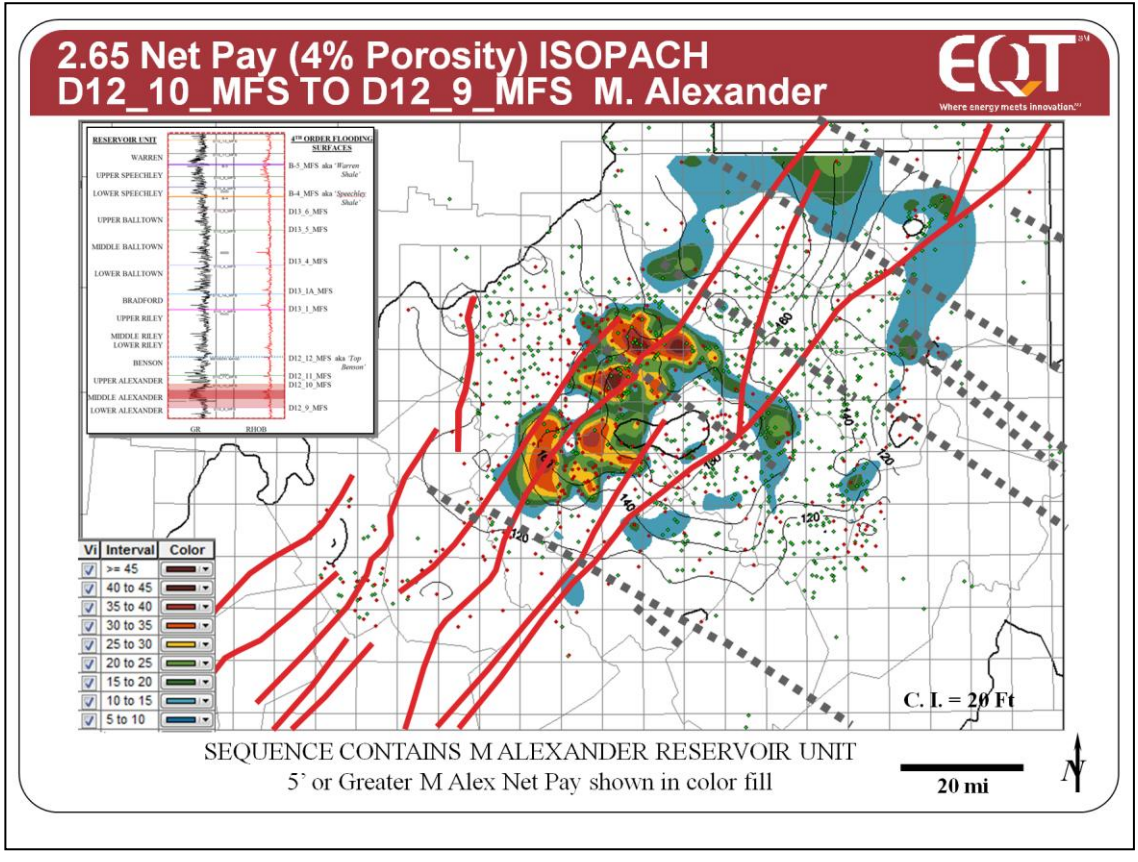
NET PAY INTERVALS MAPPED

EQT
Where energy meets innovation.SM

- D13_11_MFS to B-5_MFS (Warren)
- D13_10_MFS to D13_9_MFS (Upper Speechley)
- B-4_MFS to D13_5_MFS (Upper Balltown)
- D13_5_MFS to D13_4_MFS (Middle Balltown)
- D13_4_MFS to D13_1A_MFS (Lower Balltown)
- D13_1A_MFS to D13_1_MFS (Bradford)
- D13_1_MFS to D12_12_MFS (Rileys)
- D12_12_MFS to D12_11_MFS (Benson)
- D12_11_MFS to D12_10_MFS (Upper Alexander)
- D12_10_MFS to D12_9_MFS (Middle Alexander)
- D12_9_MFS to D12_8A_MFS (Lower Alexander)
- D12_8_MFS to D12_7_MFS (Upper Elk)
- D12_8A_MFS to D12_8_MFS (Upper Elk)
- D12_7_MFS to D12_MFS (Middle Elk?)
- D12_MFS to D11_MFS (Middle Elk?)
- D11_MFS to D10_6_MFS (Sycamore Grit)
- D11_MFS to D10_MFS (Lower Elk?)
- D10_3_MFS to D10_MFS (Lower Elk)
- D10_6_MFS to D10_3_MFS (Lower Elk)

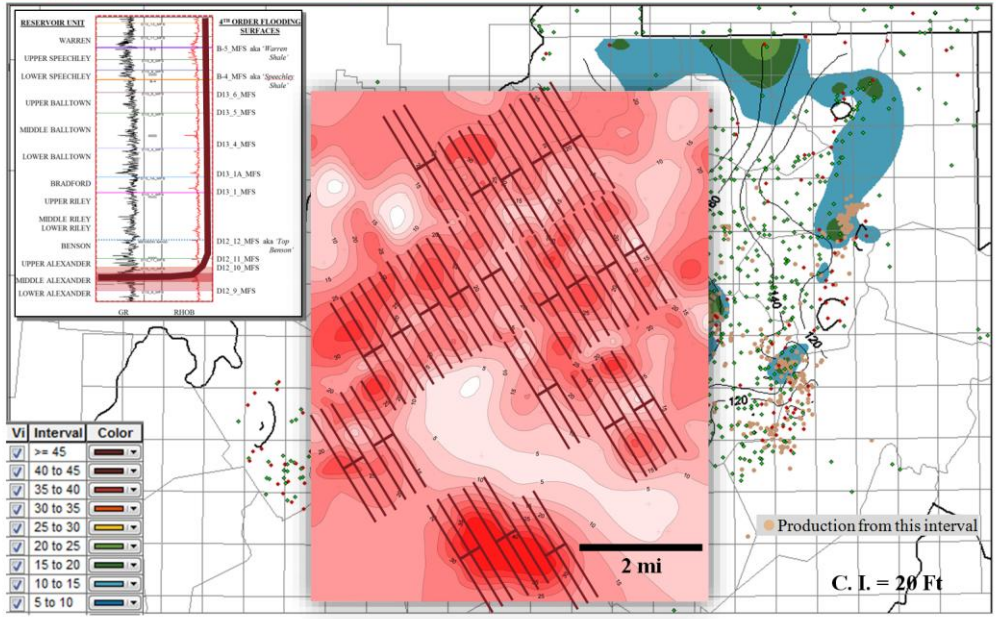


Presenter's notes: ISOPACH D12_12_MFS (TOP BENSON) TO D12_10_MFS
SEQUENCE CONTAINS BENSON AND UPPER ALEXANDER
RESERVOIR UNITS



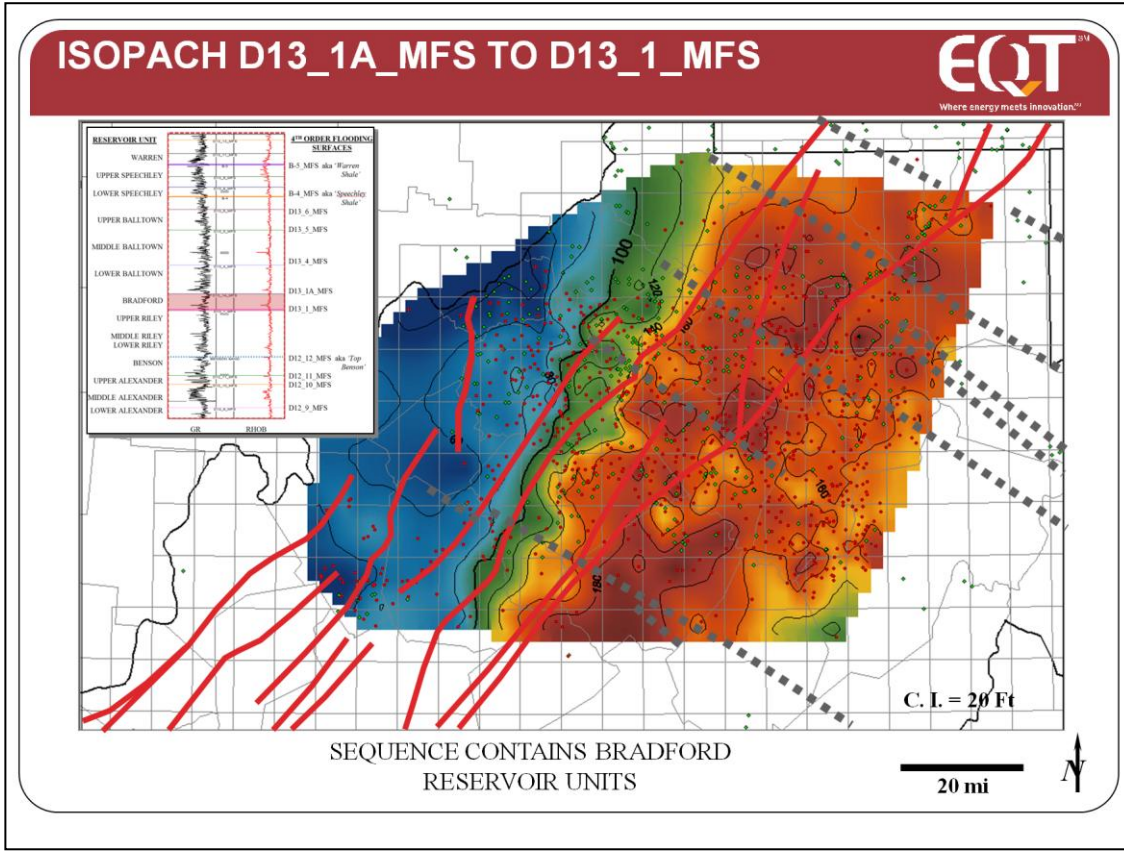
Presenter's notes: ISOPACH D12_12_MFS (TOP BENSON) TO D12_10_MFS
SEQUENCE CONTAINS BENSON AND UPPER
ALEXANDER RESERVOIR UNITS

2.65 Net Pay (4% Porosity) ISOPACH D12_10_MFS TO D12_9_MFS M. Alexander

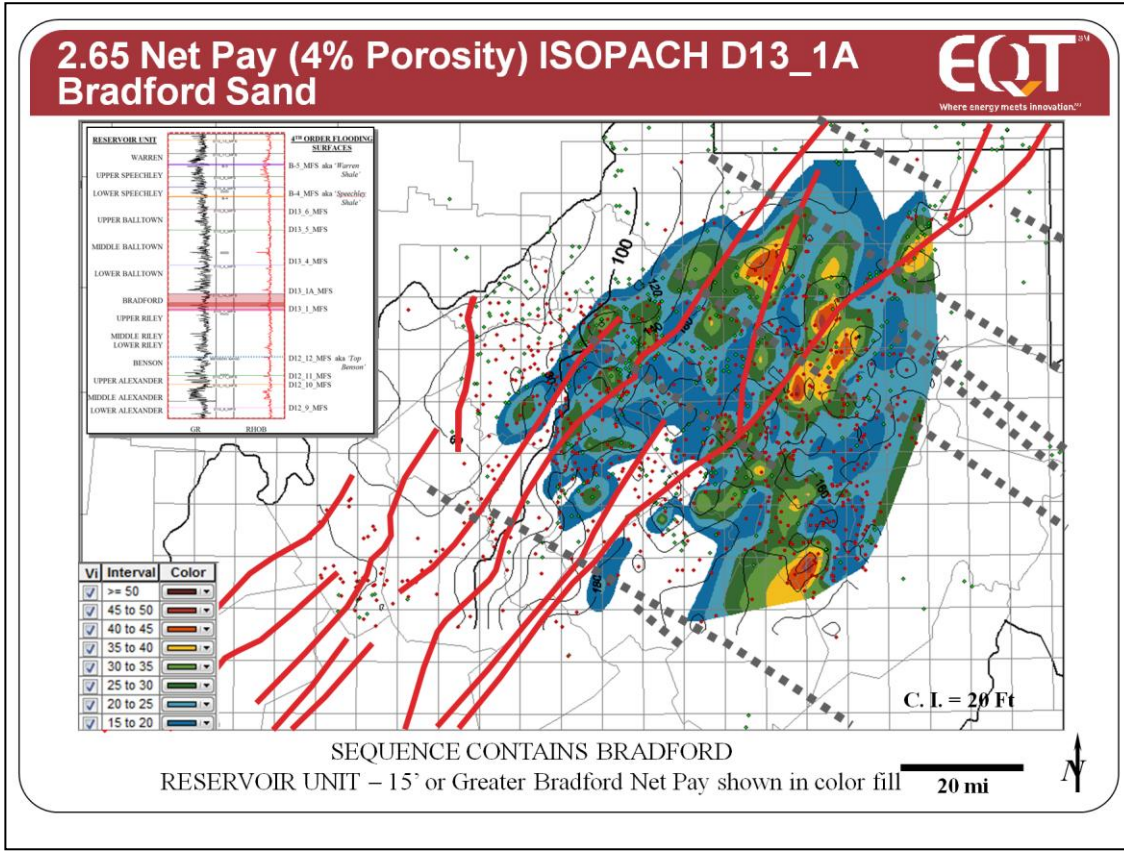


SEQUENCE CONTAINS M ALEXANDER RESERVOIR UNIT
5' or Greater M Alex Net Pay shown in color fill

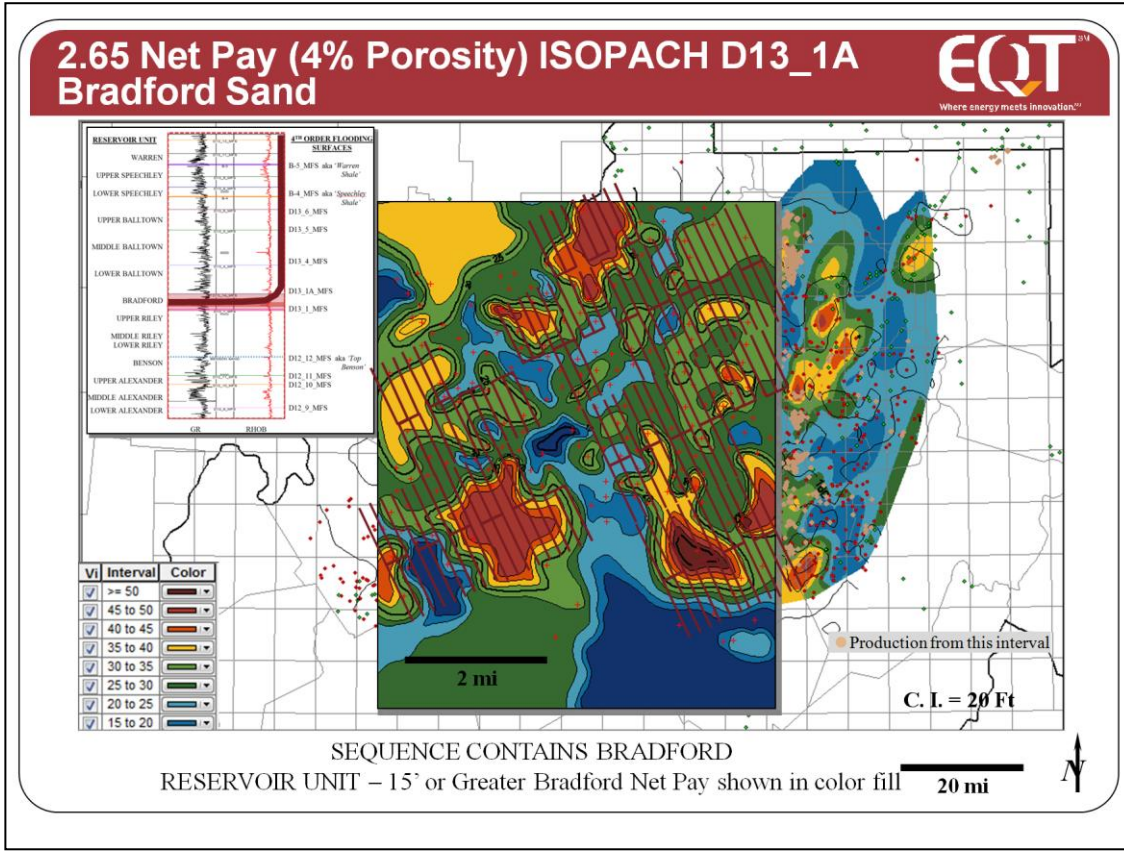
Presenter's notes: ISOPACH D12_12_MFS (TOP BENSON) TO D12_10_MFS
SEQUENCE CONTAINS BENSON AND UPPER ALEXANDER
RESERVOIR UNITS



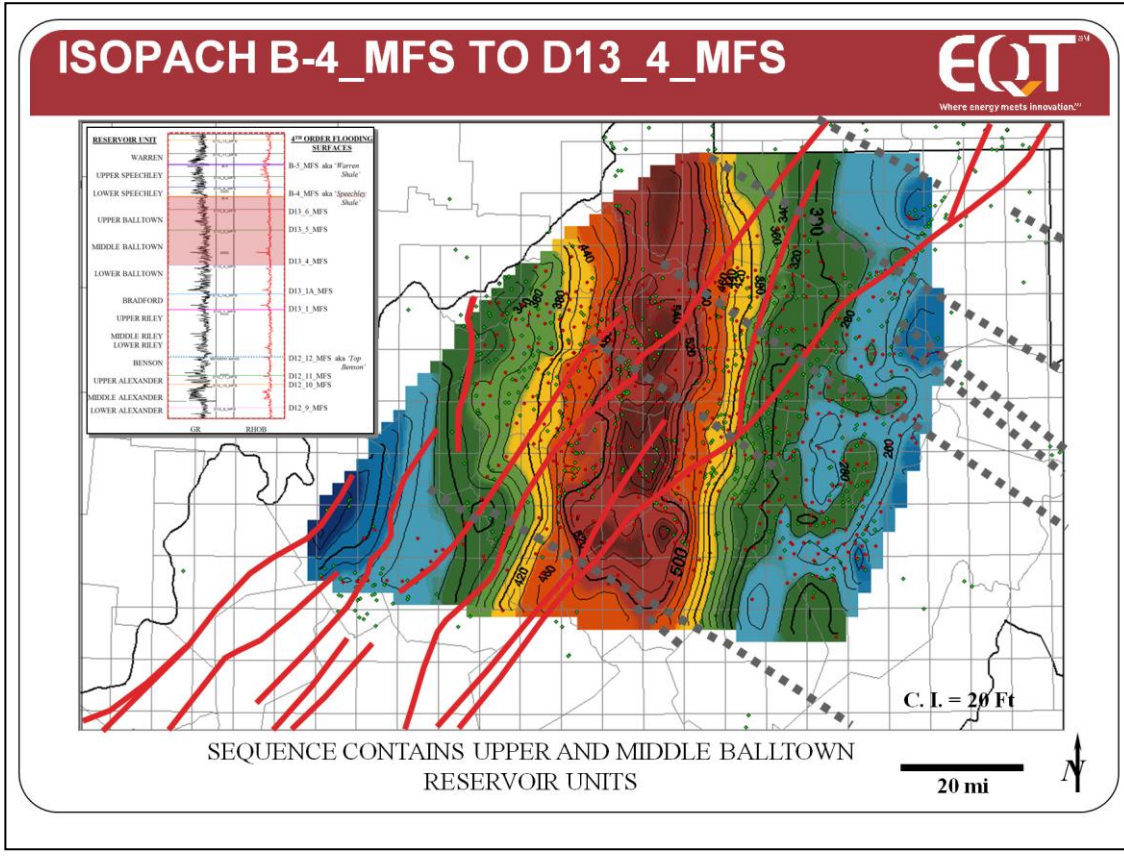
Presenter's notes: ISOPACH D13_1A_MFS TO D13_1_MFS
SEQUENCE CONTAINS BRADFORD
RESERVOIR UNITS



Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_1A to D13_1
Bradford Sand
SEQUENCE CONTAINS BRADFORD
RESERVOIR UNIT – 15' or Greater Bradford Net Pay shown in color fill

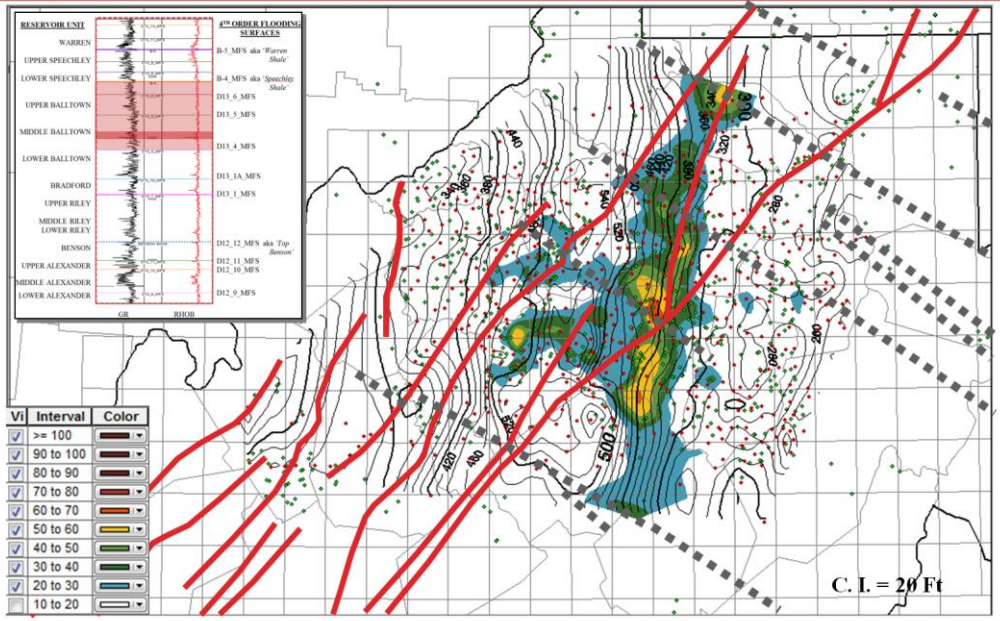


Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_1A to D13_1
Bradford Sand
SEQUENCE CONTAINS BRADFORD
RESERVOIR UNIT – 15' or Greater Bradford Net Pay shown in color fill



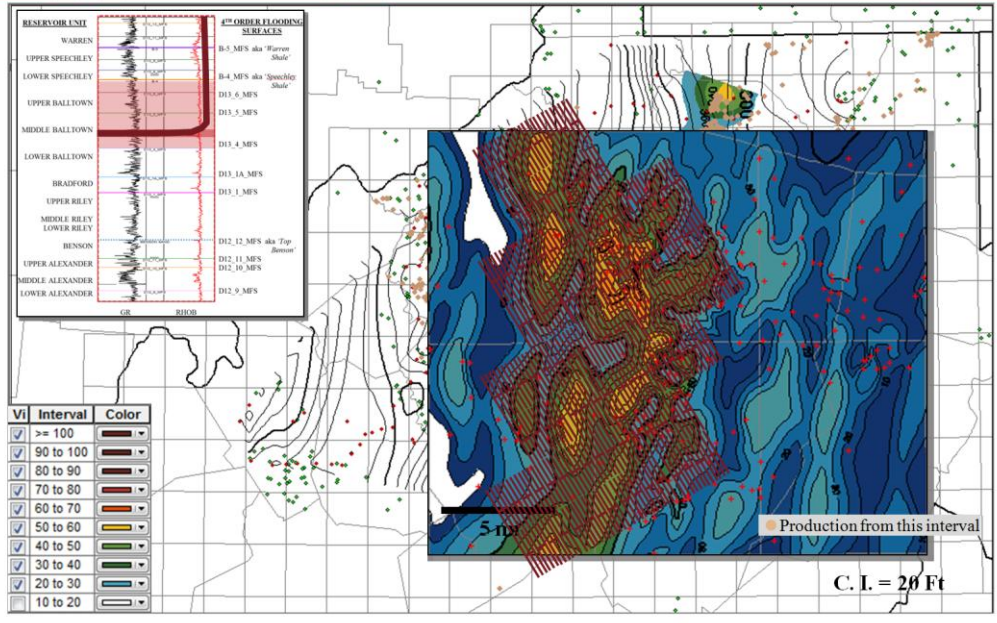
Presenter's notes: ISOPACH B-4_MFS TO D13_4_MFS
SEQUENCE CONTAINS UPPER AND MIDDLE BALLTOWN
RESERVOIR UNITS

2.65 Net Pay (4% Porosity) ISOPACH D13_5_MFS to D13_4_MFS: Middle Balltown



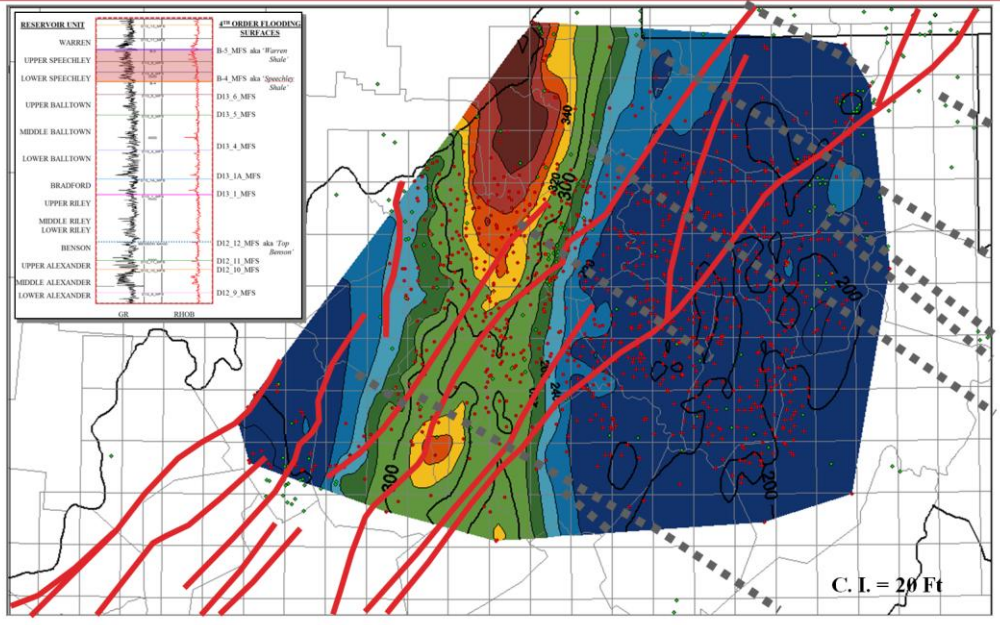
Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_5_MFS to D13_4_MFS: Middle Balltown
SEQUENCE CONTAINS MIDDLE BALLTOWN
RESERVOIR UNIT – 20' or Greater M BLTN Net Pay shown in color fill

2.65 Net Pay (4% Porosity) ISOPACH D13_5_MFS to D13_4_MFS: Middle Balltown

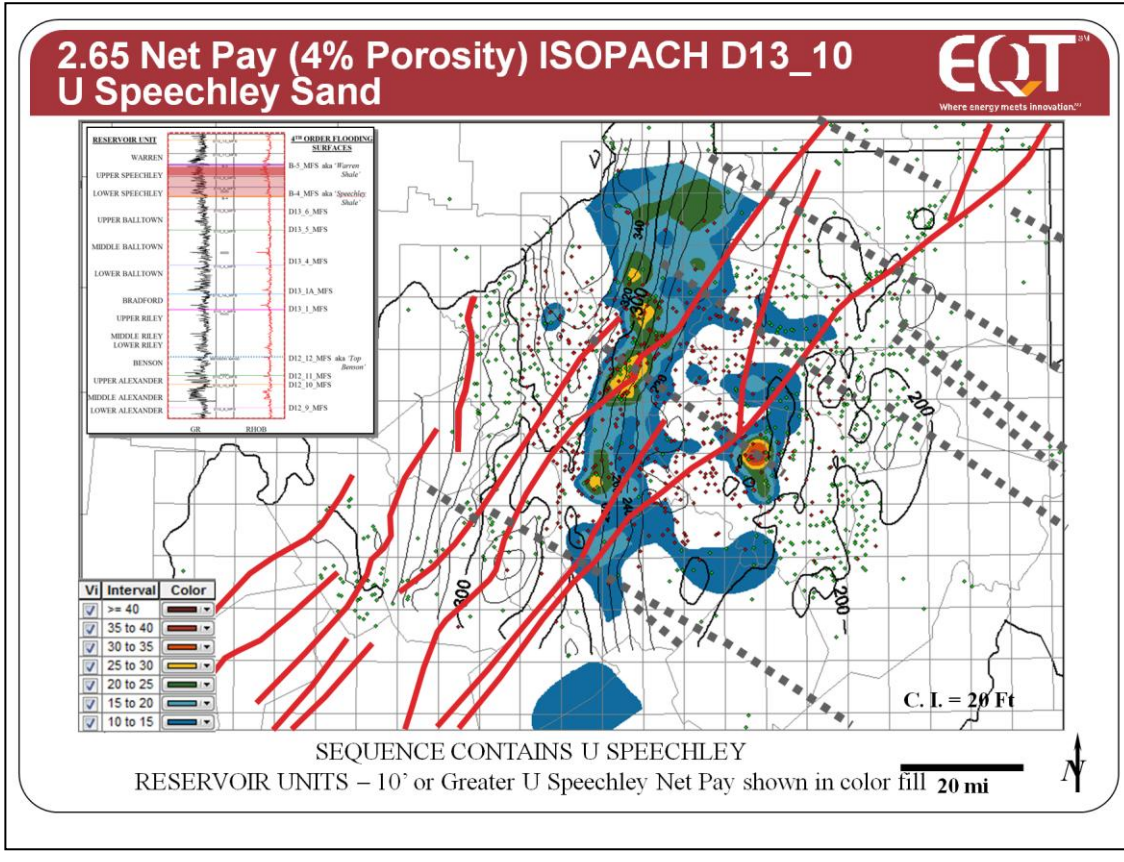


Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_5_MFS to D13_4_MFS: Middle Balltown
SEQUENCE CONTAINS MIDDLE BALLTOWN
RESERVOIR UNIT – 20' or Greater M BLTN Net Pay shown in color fill

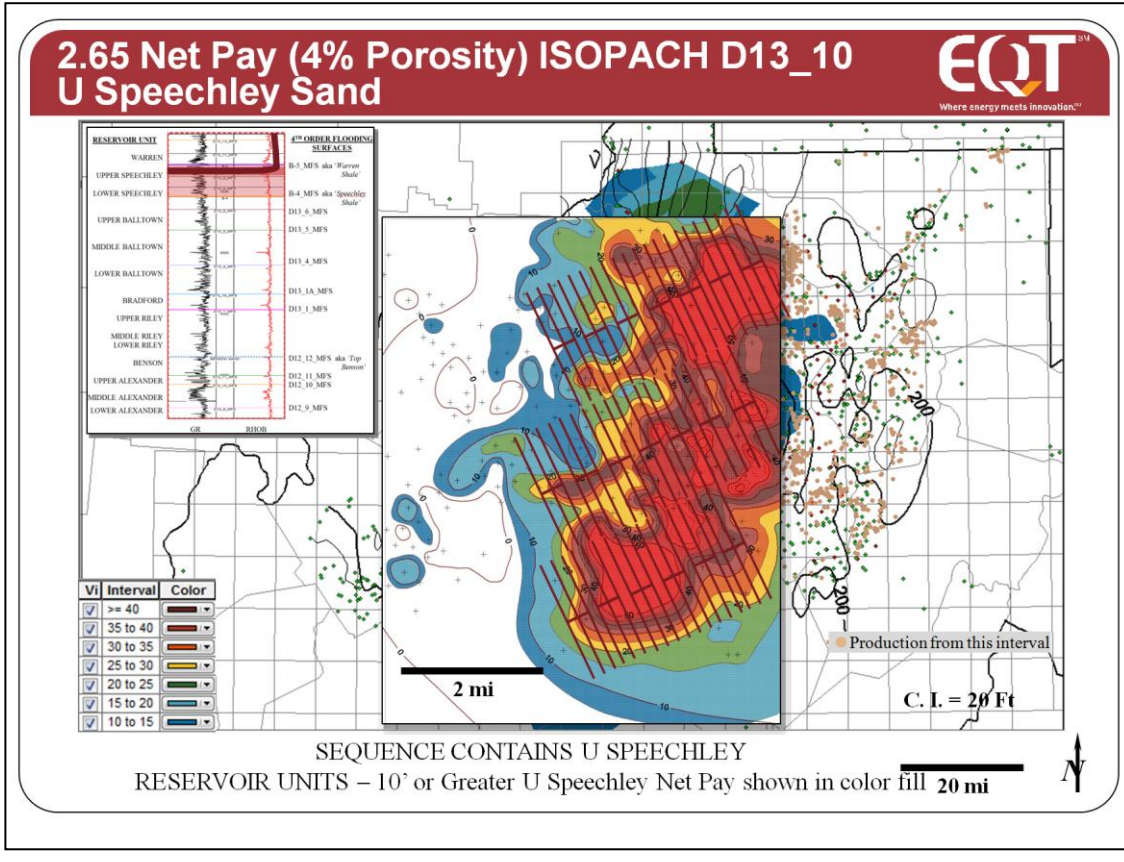
ISOPACH B-5_MFS TO B-4_MFS



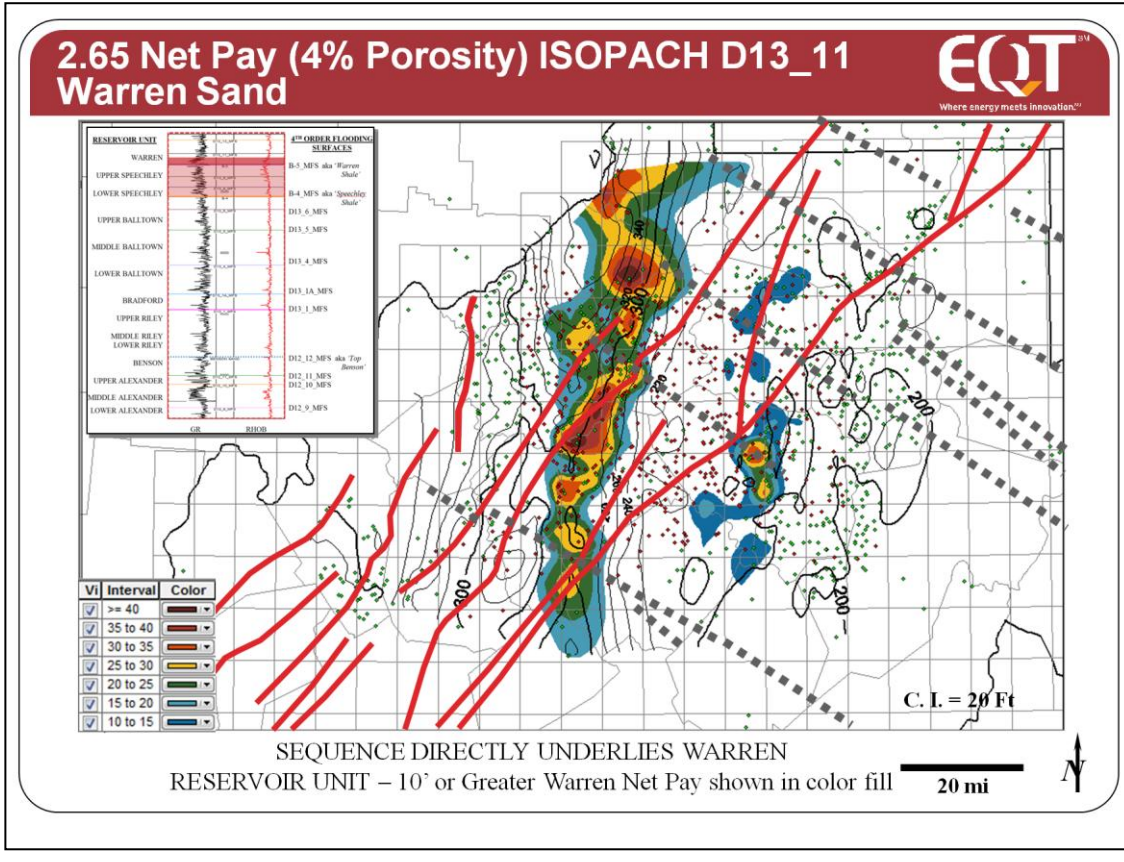
Presenter's notes: ISOPACH B-5_MFS TO B-4_MFS



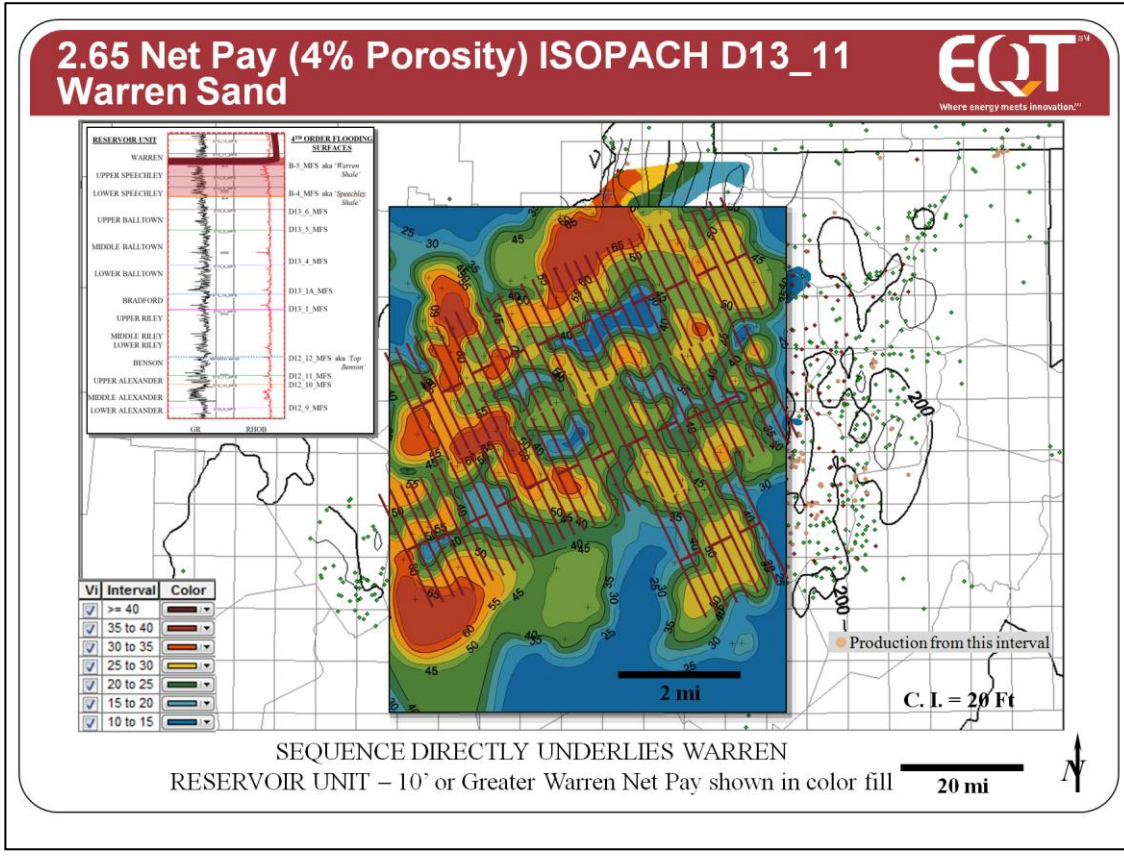
Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_10
Speechley Sand
SEQUENCE CONTAINS SPEECHLEY
RESERVOIR UNITS – 15' or Greater USpeechley Net Pay shown in color fill



Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_10
Speechley Sand
SEQUENCE CONTAINS SPEECHLEY
RESERVOIR UNITS – 15' or Greater USpeechley Net Pay shown in color fill

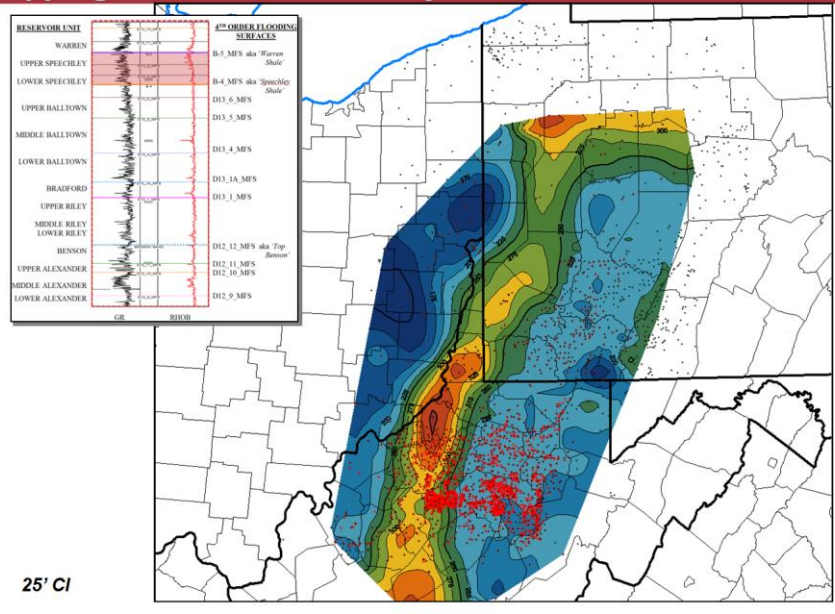


Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_
SEQUENCE DIRECTLY UNDERLIES WARREN
RESERVOIR UNIT – 20' or Greater Warren Net Pay shown in color fill
11 Warren Sand



Presenter's notes: 2.65 Net Pay (4% Porosity) ISOPACH D13_
SEQUENCE DIRECTLY UNDERLIES WARREN
RESERVOIR UNIT – 20' or Greater Warren Net Pay shown in color fill
11 Warren Sand

ISOPACH B-5_MFS TO B-4_MFS
Mapping extended into Pennsylvania



SEQUENCE CONTAINS UPPER SPEECHLEY RESERVOIR UNIT

2.65 Net Pay (4% Porosity) ISOPACH D13_10
U Speechley Sand Mapping extended into Pennsylvania

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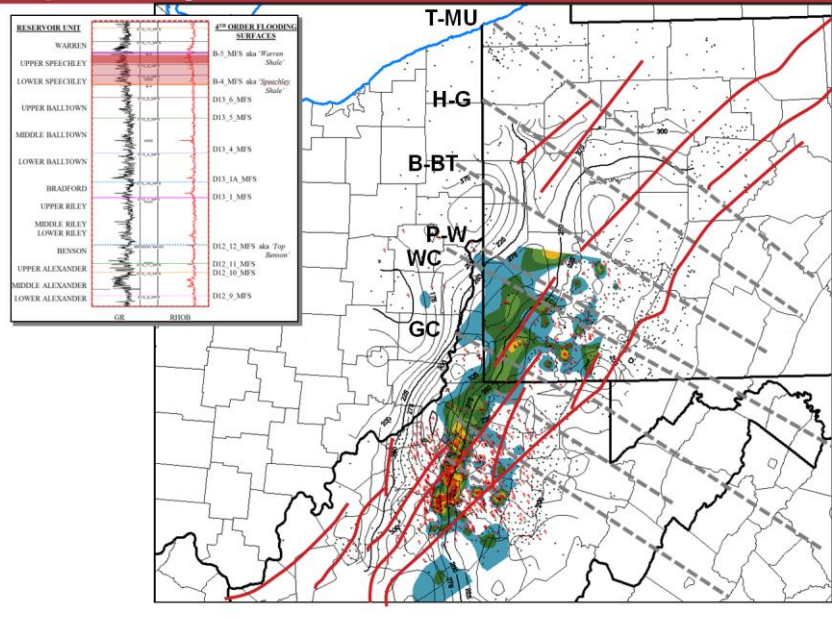

SEQUENCE CONTAINS UPPER SPEECHLEY
RESERVOIR UNIT – 10' or Greater Upper Speechley Net Pay shown in color fill

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Upper Devonian Siltstones in Northern West Virginia

- Geology and Production
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WV STRATIGRAPHIC CORRELATIONS
NORTHERN TO SOUTHERN WV

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- SPEECHLEY thru RILEYS = ENTIRE LOWER HURON SHALE SECTION
- TOP SPEECHLEY = TOP LOWER HURON
  - *B-5_MFS = D13_10_MFS ('WARREN SHALE')*
- SPEECHLEY = ~LOWER HURON SILT
  - *BASE LH SILT = B-4_MFS = D13_7_MFS ('SPEECHLEY SHALE')*
- BRADFORD = DUNKIRK (LOWER HURON SHALE 'TARGET')
  - *D13_1A_MFS to D13_1_MFS*
- TOP JAVA = TOP OLENTANGY = TOP BENSON
  - *D12_12_MFS*
- ANGOLA SHALE ~ ALEXANDER/ELK = ~PIPE CREEK SHALE
  - *D12_10_MFS*
- RHINESTREET SHALE = MIDDLE ELK SILTS
  - *12_8_MFS*

SOUTH TO NORTH CROSS-SECTION THRU WV
SHOWING 4th ORDER SEQUENCE BDYS

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SW

HURON PLAY AREA

NWV UDVNN PLAY AREA

NE

'BEREA'

'L Huron-SILT'

'TOP JAVA'

'Angola-SILT'

'SPEECHLEY'

'BRADFORD'

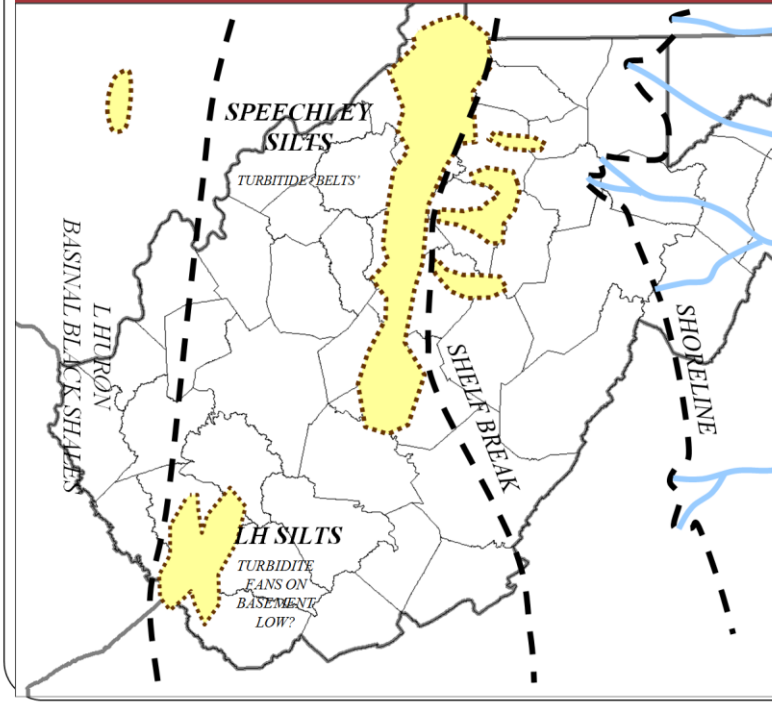
D12_12_MFS
TOP 'BENSON'

'ALEXANDER'

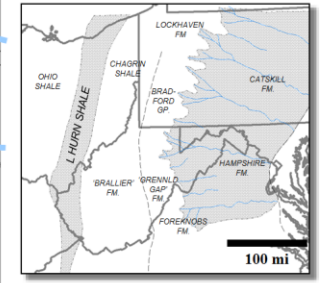
'ELKS'

ONONDAGA

PALEOGEOGRAPHY: SPEECHLEY-BALLTOWN TIME IN WEST VIRGINIA



Paleogeography "Balltown" time

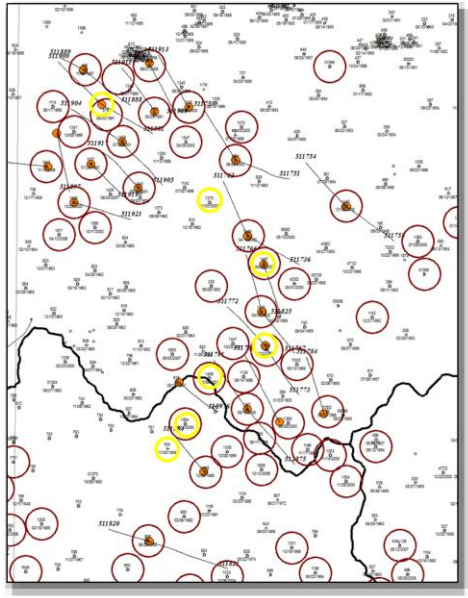


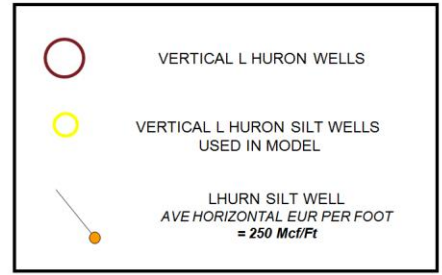
after Boswell, 1988

40 mi

N

SOUTHERN WV ANALOG
LOWER HURON SILTSTONE, MALLORY QUAD



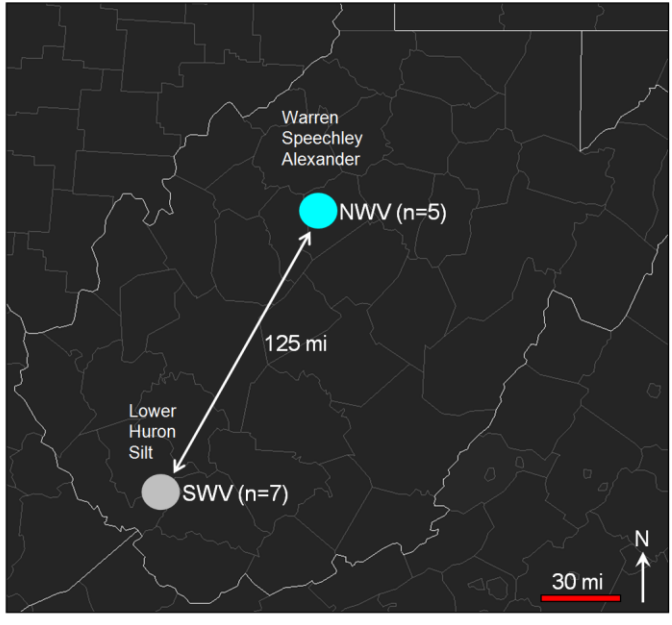


Outline
Upper Devonian Siltstones in Northern West Virginia

EQT Where energy meets innovation.SM

- Geology and Production
- Methodologies
- Mapping Results
- Producing Analogs
- **Petrophysical Model**
- Summary and Conclusions

Modeled Geologic Parameters
SWV vs. NWV



Parameters compared between 7 SWV logs and 5 NWV logs:

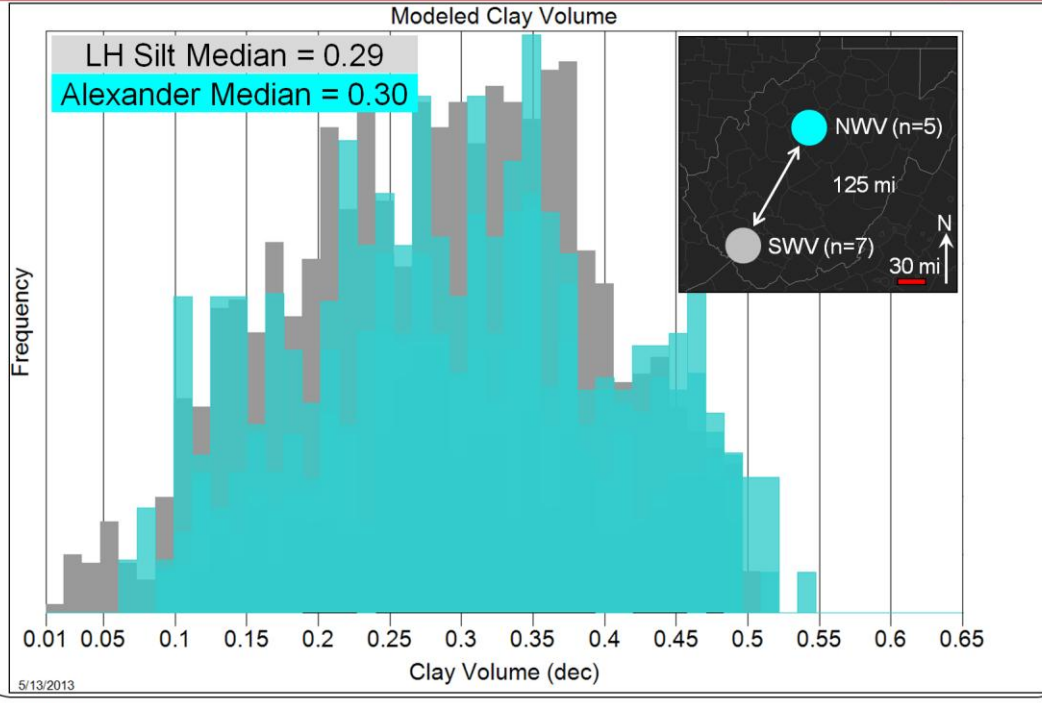
- Clay volume
- Total porosity
- Sw
- GIP

For these formations:

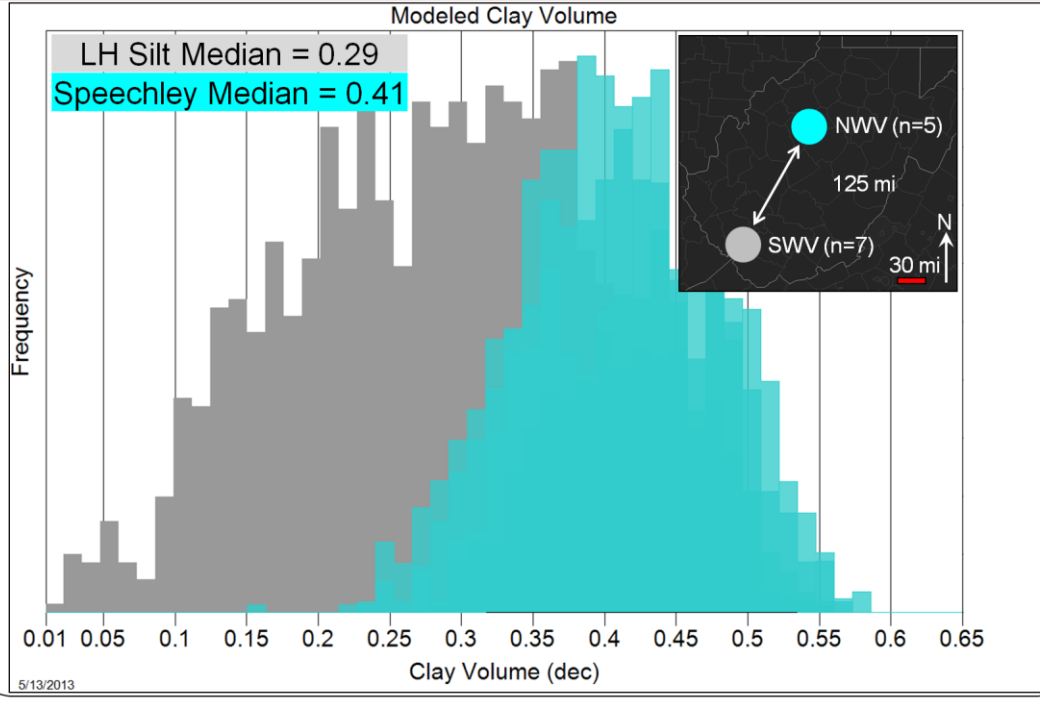
- Warren
- Speechley
- Alexander

vs. Lower Huron Silt

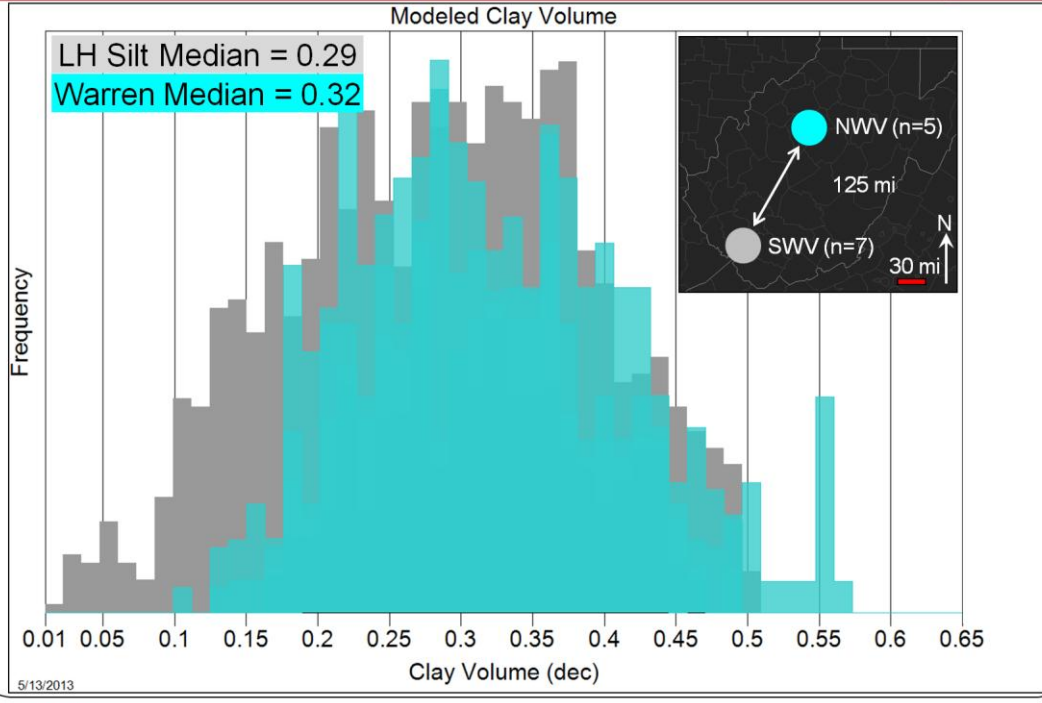
Clay Volume (LH Silt vs. Alexander)



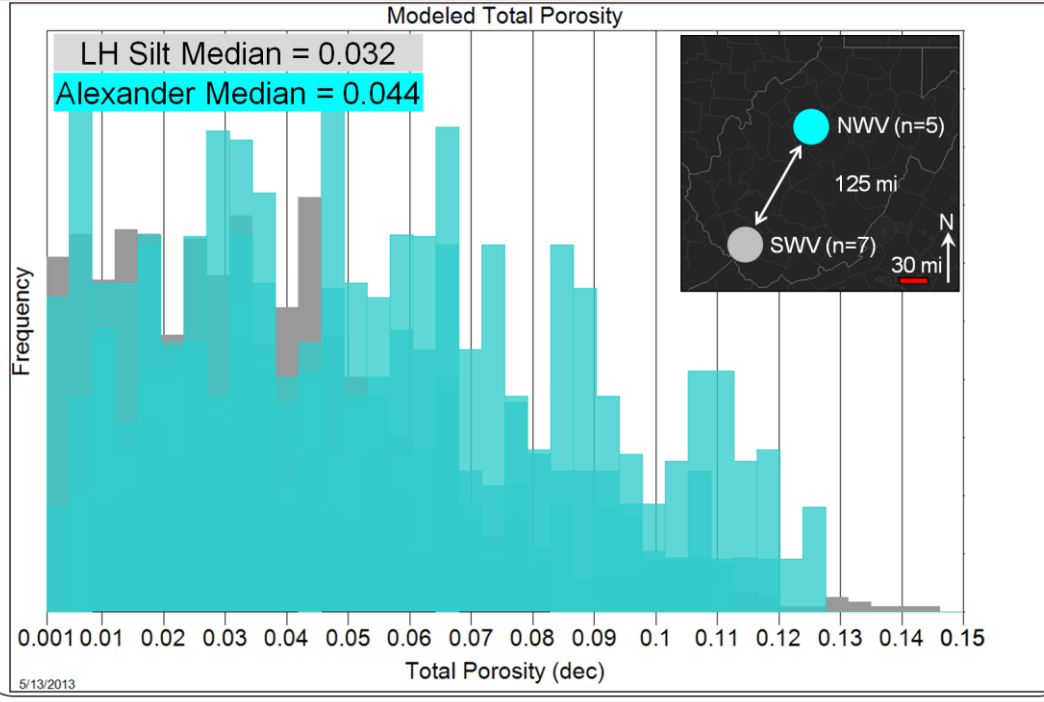
Clay Volume (LH Silt vs. Speechley)



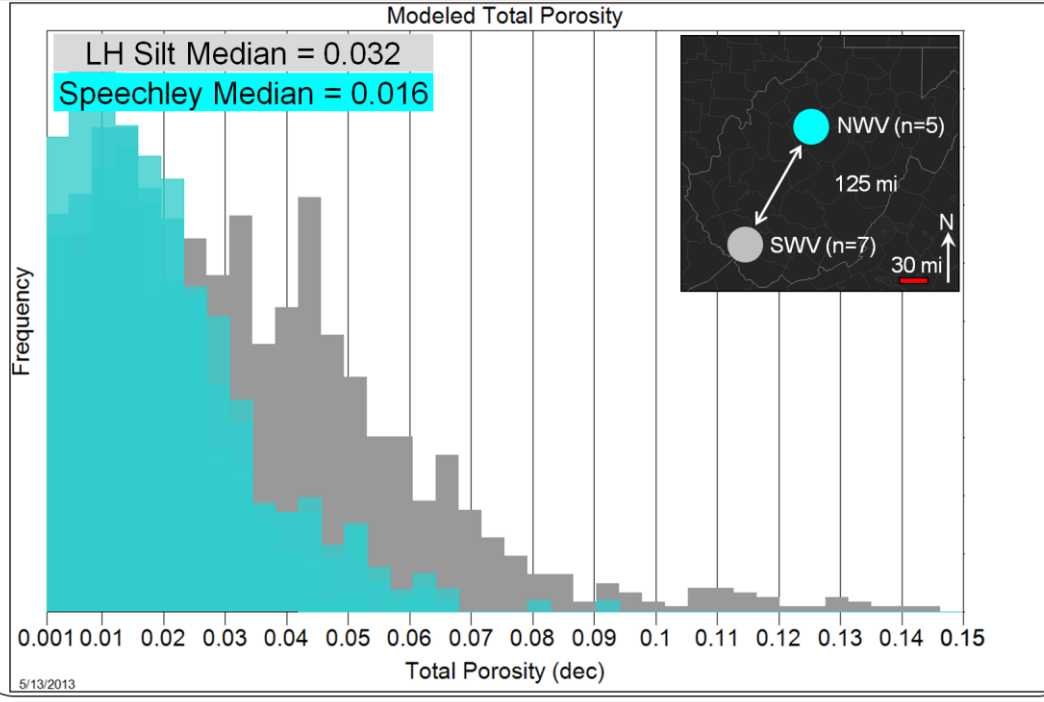
Clay Volume (LH Silt vs. Warren)



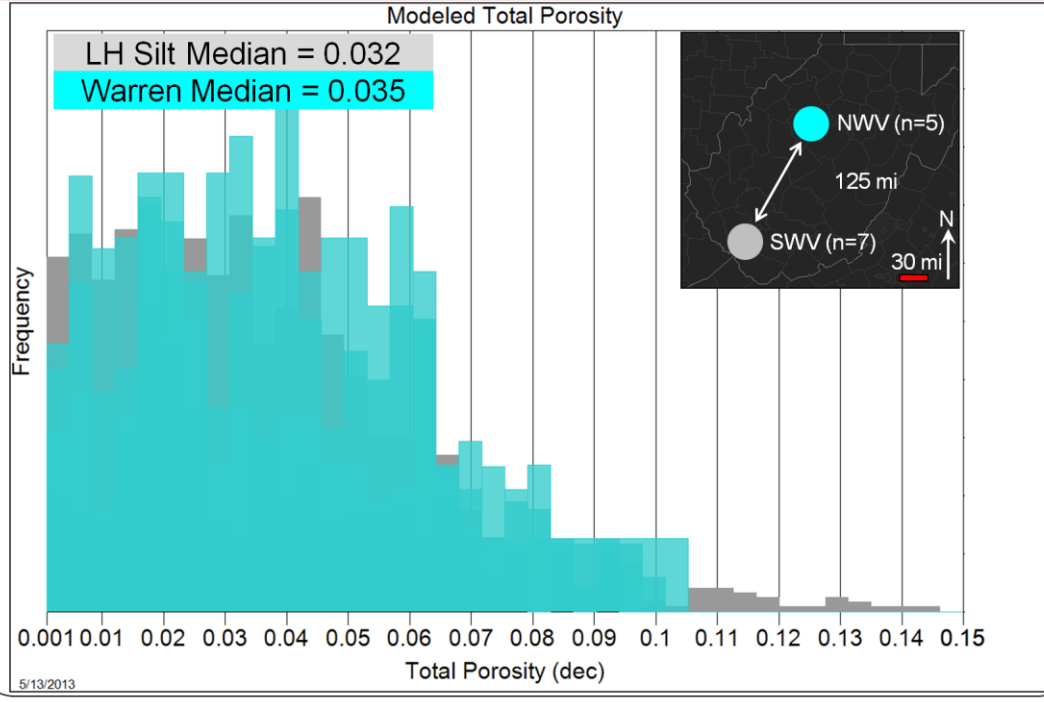
Total Porosity (LH Silt vs. Alexander)



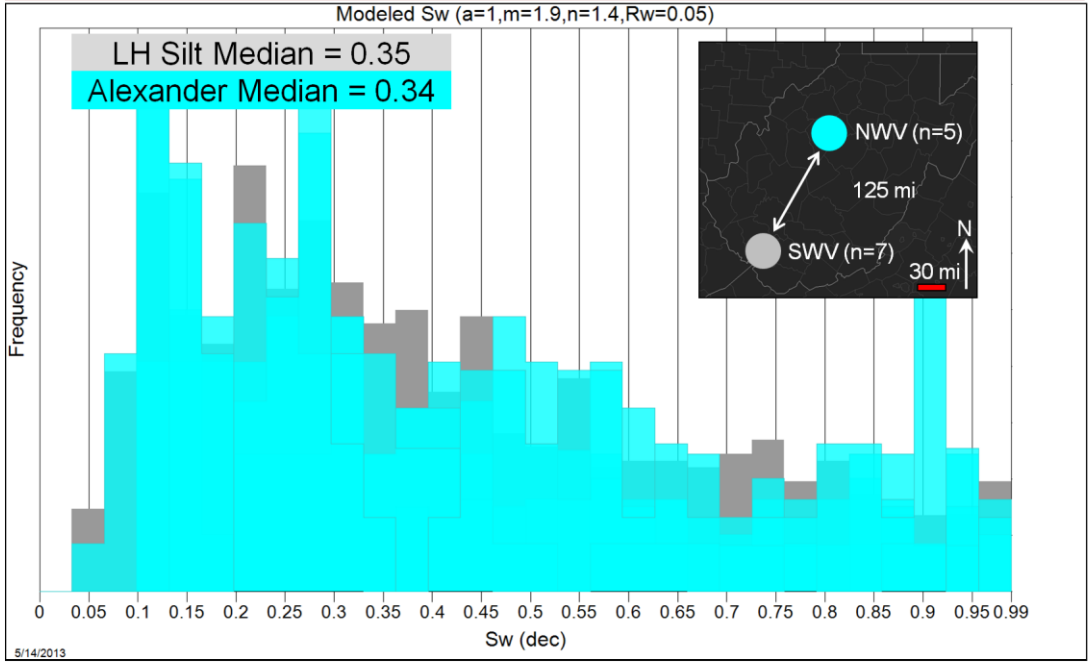
Total Porosity (LH Silt vs. Speechley)



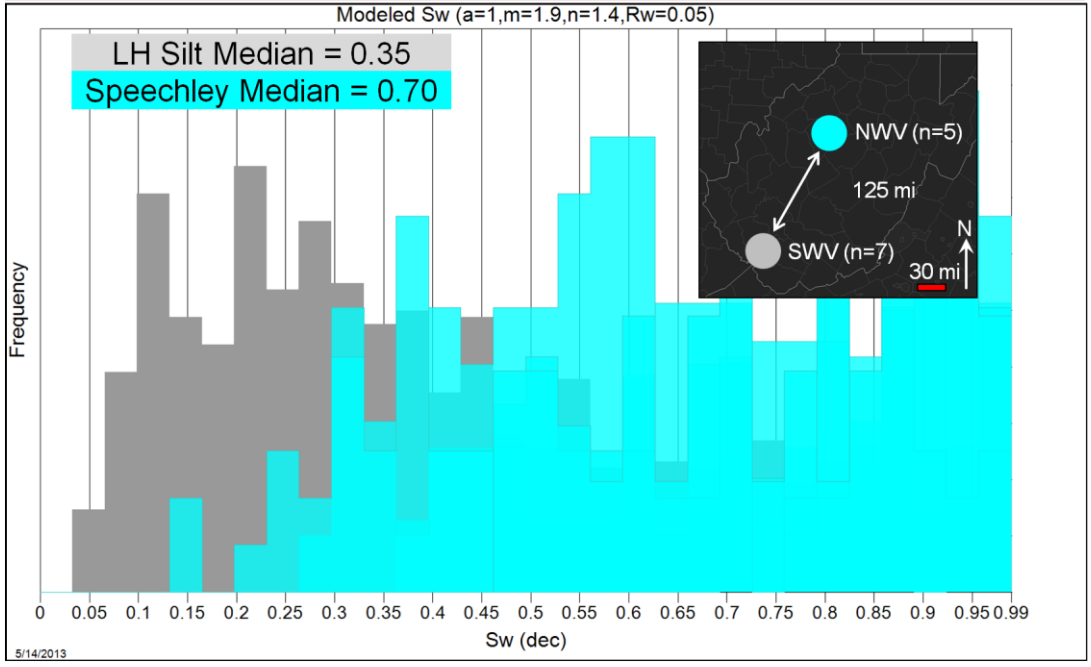
Total Porosity (LH Silt vs. Warren)



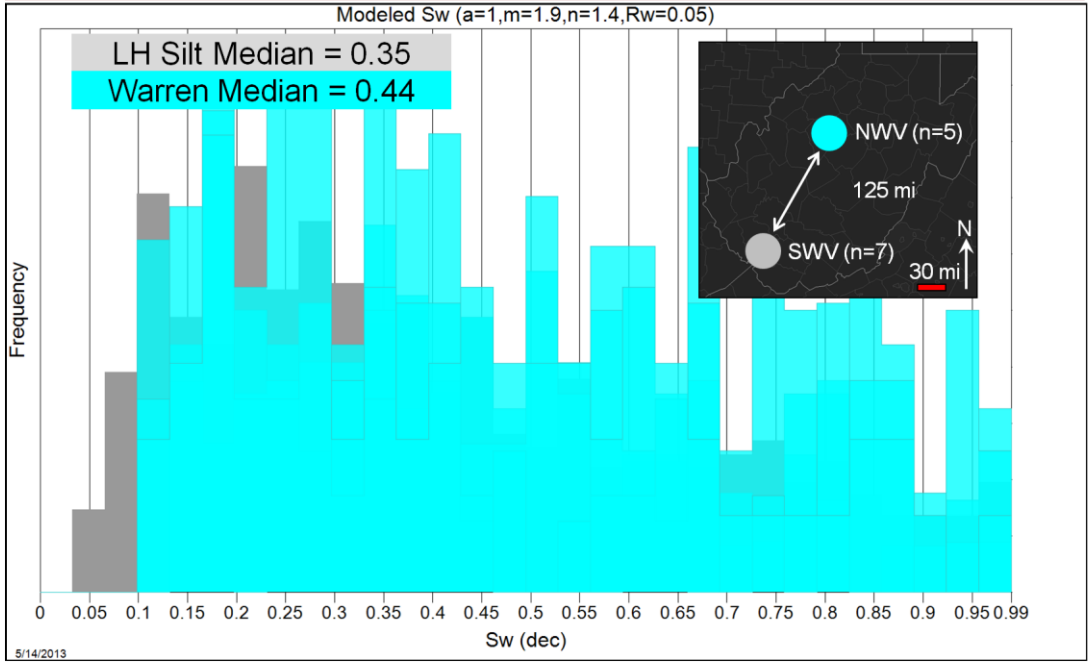
Sw (LH Silt vs. Alexander)



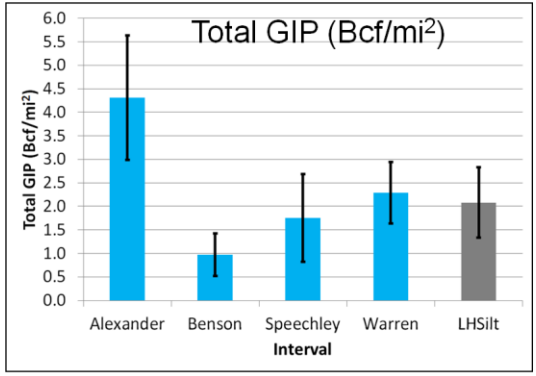
Sw (LH Silt vs. Speechley)

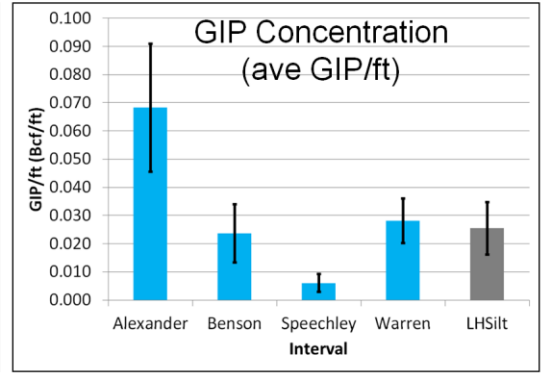


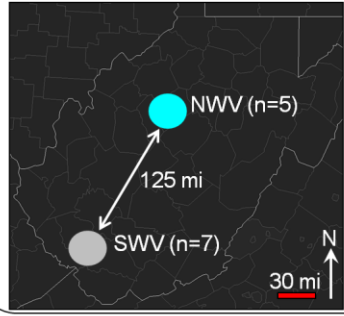
Sw (LH Silt vs. Warren)



Average GIP and GIP Concentration
SWV vs. NWV







- NWV n = 5; SWV n = 7
- SWV (LH Silt) press grad = 0.15 psi/ft
- NWV (AL,BE,SP,WR) press grad = 0.30 psi/ft
- Error bars represent standard deviation
- All GIP calculations assume an area of 1 mi^2
- Alexander shows greatest GIP and gas density

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Summary and Conclusions

- Northern WV Siltstone Reservoirs are a Potentially Huge New Gas Resource play
- Petrophysical parameters are comparable for both Southern (LH Silt) and Northern WV Silt reservoirs
- Volumetric reserves calculations for Lower Huron Silt wells do not match EURs (~3x)
- Poor appearing wells (from logs) can perform very well
- Old verticals have been offset successfully by new laterals
- Lateral Heterogeniety (compartmentalization) is best accessed through horizontal drilling approach
- 'Huron Silt' style Horizontal drilling and completion has never been applied to No WV Siltstone reservoirs

Acknowledgements

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- EQT Production Company
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